AREAL FREQUENCIES OF HAIL AND THUNDERSTORM DAYS IN ILLINOIS

STANLEY A. CHANGNON, JR.

Illinois State Water Survey, Urbana, Ill.

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ABSTRACT

Hail and thunderstorm statistics for the 1951–60 period obtained from 119 U.S. Weather Bureau stations in Illinois were combined with crop-hail insurance data for this same period for performing a detailed climatological investigation of the frequencies of hail days and thunderstorm days in Illinois. In the crop-growing season thunderstorms occur on 1 out of every 2 days on the average and hail occurs somewhere in Illinois on 4 out of every 10 days. The hail-thunderstorm areal ratio for Illinois is 68 percent as compared with point ratios varying from 3 to 7 percent. It appears that some thunderstorms may not contain hail since 32 percent of all the thunderstorm days had no hail reported at the surface anywhere in Illinois. Thunderstorms on days without hail most frequently occurred in southern Illinois and were associated more frequently with air mass and warm frontal conditions than were the hail-thunderstorms. This research also has shown how "Days With" data from cooperative substations of the Weather Bureau can be used to enlarge our knowledge of regional climatology.

1. INTRODUCTION

In recent years much has been written about the reliability of the commonly referred to hail-thunderstorm ratio, especially since the point observation of thunderstorms represents an areal integration whereas the observation of hail represents occurrence only at the point [10]. Attention also has been given to the question of whether all thunderstorms contain hail aloft during their lifetimes [8]. Hail research in Illinois has produced some information which is pertinent to these issues. This paper summarizes the results derived from a comparative analysis of the simultaneous daily occurrence of hail days and thunderstorm days in Illinois during the March-October period and the mid-May to mid-September period.

One phase of recent Illinois hail studies has been concerned with a basic question concerning the statistical relationship between thunderstorms and hailstorms. This question is: How frequently in the thunderstorm season (March-October) and in the growing season (mid-May to mid-September) do days with thunderstorms in a given area give hail in that area? Since the average areal size of the two events varies [1, 3] and thereby favors thunderstorm frequency, and since the method of recording the two events also favors thunderstorms, any system of incidence comparison requires the integration of occurrence data over a large area in order to obtain true frequencies. To this end, this particular investigation used the State of Illinois as the area of comparison. The frequency of hail days and thunderstorm days was based on occurrence anywhere within the 56,000-square-mile area of the State. In this paper particular attention is given to the data concerning dates which were thunderstorm days but were not hail days.

2. DATA

The analysis utilized a large quantity of data pertaining to the incidence of hail and thunderstorms in Illinois during the 1951–60 period. The principal sources of data included the original records of approximately 110 U.S. Weather Bureau cooperative substations, the records of 9 first-order stations in the Illinois area, and the hail insurance claim records of the Crop-Hail Insurance Actuarial Association. The Weather Bureau records served as the source of thunderstorm data. The Weather Bureau station data and the records of the insurance companies were the sources of the hail data. In central and northern Illinois the insured lands represented approximately 5 percent of the total area, but less than 1 percent of the southern Illinois area.

Before any date was defined as a hail day or a thunderstorm day, its frequency of point reports had to exceed a given number of reports in order to eliminate potential observer errors in the recording of the dates of hail or thunder. In order for a date to be classified as a thunderstorm day at least three stations had to report thunder. The occurrence of three or more station reports of thunder on a single day was selected to define thunderstorm days in order to minimize errors in the reporting of dates with thunder by the cooperative observers. Careful examination of the original records revealed many instances when a date had a large number of station reports of thunder and the ensuing date and/or preceding date had only one or two reports of thunder. Eighty-two percent of the total number of dates with one or two station reports of thunder in the 1951–60 period occurred on either the day preceding or the day following a date with three or more thunder reports. On many of these dates examination of

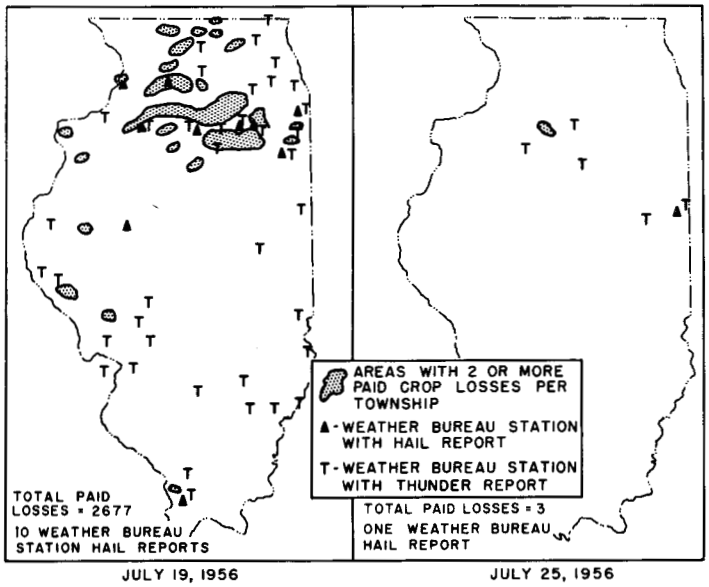

FIGURE 1.—Examples of major (left) and minor (right) hail days in Illinois during 1956.

the hourly rainfall data for the State revealed that no rain had occurred within several hours of the preceding or following day, and therefore, it appeared quite likely that the dates of these thunder reports were erroneous and were a result of either observer error or observer confusion in reporting the actual date of thunder occurrence. For a date to be listed as a hail day there had to be at least three paid hail insurance claims or one or more Weather Bureau station reports of hail. Examples of thunderstorm days with large and small numbers of hail reports and paid crop losses are shown in figure 1. One Weather Bureau station report of hail was selected as an adequate number to define a hail day, as opposed to the requirement of three station reports for a thunderstorm day, because hail is a more infrequent event at a point and it normally receives greater observer attention than does thunder. It is believed that these circumstances eliminate most observer errors in reporting dates of hail incidence.

The adequacy of the thunderstorm day sampling is partially revealed by comparing the frequency of thunderstorm days, as based on the three or more station reports, with the number of thunderstorm days defined using two or more station reports of thunder. The use of one or more station reports to define a thunderstorm day does not provide a satisfactory test of the frequency based on three or more reports because a large number of the single reports are errors by the cooperative observers. In the May 16–September 15 period there are normally 77 thunderstorm days (table 2), as defined by the three or more station reports of thunder. If thunderstorm days are defined by two or more station reports of thunder, the seasonal total increases to 83, which is only an 8 percent increase. The definition based on one or more thunder reports for a thunderstorm day raises the average seasonal number to 94. The hail-thunderstorm ratio for Illinois changes from 68 percent, as based on three or more reports, to 64 percent when based upon two or more station reports. This slight difference indicates adequacy in the thunderstorm day frequency as based upon the definition of the thunderstorm day as a day with three or more stations reporting thunder.

Even with the large amount of hail data employed, it is possible that a few hail days occurred which were not detected. Therefore, the hail statistics presented herein must be considered as a conservative climatological estimate of hail day frequencies. However, two investigations were performed which indicated a nearly complete sampling of hail days.

A hail-reporting network consisting of approximately 1,100 cooperative observers, who were mostly farmers, was operated in east-central Illinois during the thunderstorm seasons of 1959, 1960, and 1961 [16]. These 1,100 observers were quite evenly dispersed throughout a 22,250-square-mile area, and each observer reported the incidence of hail of any size. The dates of hail days in 1959 and 1960, as determined from this reporting network, were compared with the hail dates obtained from the Weather Bureau stations and insurance data in the same years to obtain an estimate of the adequacy of the hail days sampling based upon the Weather Bureau and insurance data.

In the March–October period of 1959 and 1960, the hail network recorded 38 and 36 hail days, respectively, as compared with the Weather Bureau-insurance data listing of 63 and 71 hail days, respectively. Thus, in each of these two years the hail network identified less than 60 percent of the hail days in the State identified by the Weather Bureau-insurance data. Furthermore, the network data did not record any dates of hail which were not identified as hail days by the Weather Bureau and insurance data for the State.

Sampling adequacy for hail days was evaluated also by a statistical investigation which compared the frequency of hail days for different numbers of Weather Bureau stations or data sources. The average number of hail days in the crop-growing season based upon data from the 119 Weather Bureau stations used in this study was 31. Data

TABLE 1.—*Average number of hail days in the crop-growing season derived from data from various numbers of Weather Bureau stations in the 1951–60 period*

Hail reporting stations		Hail days	
Number	Percentage reduction from total	Average number	Percentage reduction from total
119	0	31	0
107	10	30	3
95	20	28	10
83	30	24	23
71	40	20	36
60	50	16	48

from 10 percent of these stations were deleted using a random station selection procedure, and a new average number of hail days was computed based upon the data from the remaining number of stations. This procedure was repeated for 10 percent intervals until only 50 percent of the stations were used to compute an average. Sampling adequacy in the data for hail day frequencies would be indicated by this method if only minor percentage reductions in the number of hail days occurred with the first one or two percentage reductions in the number of stations. The percentages obtained from this procedure are shown in table 1, and these results indicate near adequacy in the sampling based upon data from the 119 Weather Bureau stations.

TABLE 2.—*Average and extreme frequencies of thunderstorm days and hail days during two seasons*

	Thunderstorm season, March–October, 245 days	Crop-growing season, May 16–Sept. 15, 123 days
Thunderstorm days		
Average number of days	123	77
Maximum number of days	159 (1954)	87 (1955)
Minimum number of days	107 (1952)	68 (1953)
Average expressed as percent of total days	50	63
Hail days		
Average number of days	84	53
Maximum number of days	115 (1956)	84 (1956)
Minimum number of days	59 (1951)	36 (1951)
Average expressed as percent of total days	34	43
Percent of thunderstorm days which are not hail days	32	31

3. CLIMATOLOGICAL FINDINGS

The climatological averages and extremes for hail days and thunderstorm days in the thunderstorm season (March–October) and in the crop-growing season (May 16–September 15) are presented in table 2. Thunderstorm days occur in Illinois on 50 percent of the days in the March–October period; this percentage increases in the crop season to 63 percent.

In the March–October period hail occurs on the average on 84 days, which represents 34 percent of the total possible days. Hail days occur more frequently in the crop-growing period, when 43 percent of all days experience hail somewhere within the State. The average of 53 hail days in Illinois during the growing season represents a significant increase from previously recorded values for the State. Lemons [9] listed an average State value of 16 days; Visher [15] indicated an average of 10 to 15 days; and Stout [13] listed 36 hail days as an average number in Illinois during the growing season. The frequency represented by Stout [13] was based upon insurance data and a hail day was defined as one with 20 or more insurance claims.

Other table 2 values of particular interest are those which express the percentage of Illinois thunderstorm days which were not hail days. Nearly one-third of the thunderstorm days in the 245-day thunderstorm season did not have hail. The frequencies of hail days and thunderstorm days were greater in the crop-growing season, and the percentage of thunderstorm days without hail remained the same. Every hail day during this 10-year period was also a thunderstorm day, although on a few spring days some stations reported hail and no thunder. Changnon [2] has shown that on the long-term average from 5 to 20 percent of the hail days at various locations in Illinois are not thunderstorm days. Shands [11] reported similar findings for Iowa.

4. POINT VS. AREAL HAIL-THUNDERSTORM RATIO

A report on the hailstorm climatology of Illinois by Huff and Changnon [7] contains data that indicate the hail-thunderstorm ratios in Illinois vary from 3 to 7 percent. This finding is based on point averages for the thunderstorm season. Thus, the difference between 97 to 93 percent and 32 percent of the thunderstorm days without hail (table 2), as derived from the State areal ratio, indicates the magnitude of difference between point and areal hail-thunderstorm ratios. Shands' [11] data for the growing season in Iowa, an area almost equal to Illinois, shows that on the average 85 thunderstorm days occur as compared with 33 hail days. Thus, the Iowa areal hail-thunderstorm ratio is 39 percent as compared with 69 percent in Illinois. This difference in ratios is largely the result of differences in the hail day frequencies which were 33 in Iowa and 53 in Illinois (table 2). The hail findings in Iowa were based upon data from all Weather Bureau stations in Iowa; thus, the difference in State frequencies is primarily due to the greater areal sampling of hail incidence in Illinois provided by the insurance data, since all Weather Bureau station data available in Illinois also were employed.

For the entire State the average frequency of hail days in the crop season varies from 100 to 50 times as great as the average frequency at random points within Illinois. For the thunderstorm season the areal-point ratio in Illinois varies from 30:1 to 45:1. Shands [11] using substation data in Iowa expressed a ratio between areal and point frequencies of hail days of 22:1. Harrison and Beckwith [5] indicated that for an area around Denver consisting of about 1,200 square miles the areal frequency of hailstorms was about 11 times as great as the point frequency. For the growing seasons of 1959–61, the central Illinois hail-reporting network [16] averaged 12 hail days per season over 22,250 square miles, and this is an areal-point ratio of about 16 to 1. Therefore, the Colorado, Iowa, and Illinois findings indicate that the hail-thunderstorm ratio is strictly a function of the size of the area investigated and the density of observations within the area.

5. HAIL PRODUCTION BY THUNDERSTORMS

Although the hail-thunderstorm climatological data indicate that not all thunderstorms produce hail at the

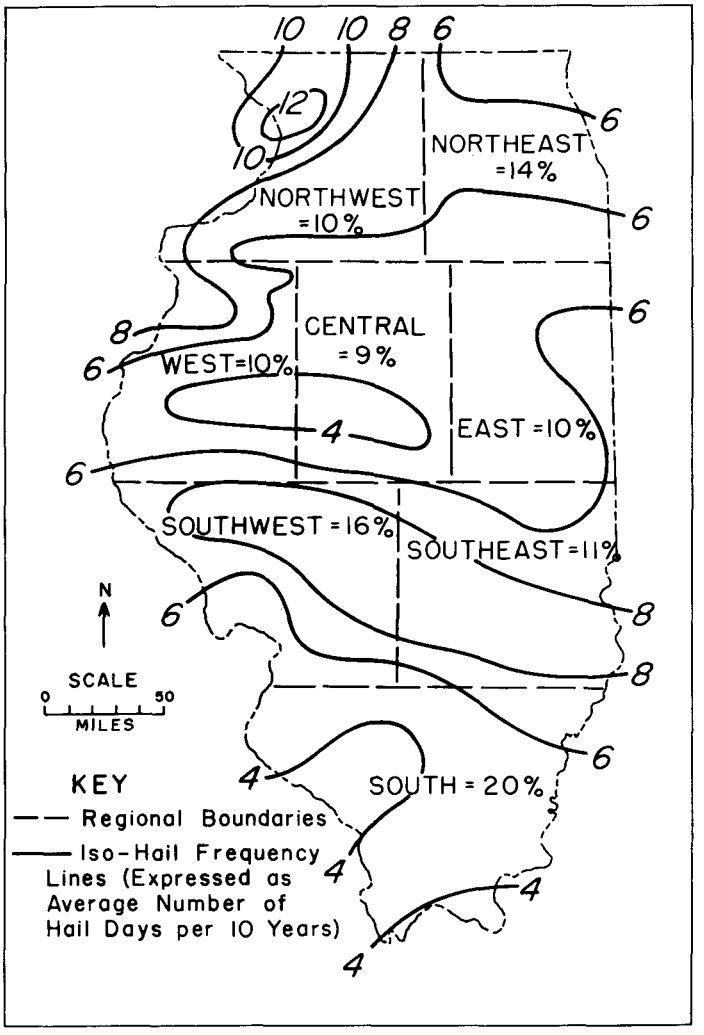

FIGURE 2.—Regional percentages of total thunder reports on no-hail thunderstorm days and summer average hail distribution in Illinois based upon point data.

ground, the findings cannot be construed as proving or disproving whether hail exists aloft in all thunderstorms. However, of the 10-year total of 242 thunderstorms days which were not hail days in the crop-growing season, more than 50 percent had 13 or more stations reporting thunder. By assuming that each of the 119 reporting stations represents about 450 square miles of Illinois, it appears that on 121 days in the 1951–60 period thunderstorms were present over approximately 5,800 square miles, or 10 percent of Illinois, and yet no hail was reported. On 21 days more than 25 percent of all the reporting stations in the State recorded thunder on days with no surface hail occurrences. Practical consideration of these facts makes it appear questionable that each of the many thunderstorms undoubtedly occurring on these days produced hail aloft when no hail appeared anywhere at the surface of such extensive areas.

Recent research by Wilk [17] concerning the detectability of hailstorms in central Illinois using 3-cm. radar revealed that 39 percent of approximately 500 thunderstorm echoes measured during a 3-year period did not contain hail aloft. This percentage of no-hail thunderstorms is in close agreement with the climatological findings for hail at the surface which was 32 percent (table 2).

6. CHARACTERISTICS OF NO-HAIL THUNDERSTORM DAYS

The data associated with the no-hail thunderstorm days in the growing seasons of 1951–60 were analyzed in further detail. One phase of this analysis concerned the regional distribution of stations which reported thunder on the no-hail thunderstorm days, and another concerned the type of synoptic conditions associated with these thunderstorm days.

To measure regional variations, the State was divided approximately along U.S. Weather Bureau [14] climatological boundaries into eight regions (fig. 2), and each region contained about 15 stations reporting thunder and hail. In figure 2 the summer average hail distribution pattern, as described by Stout [12], also has been superimposed. In the 1951–60 period, a total of 3,083 stations reported thunder on the 242 days when no hail occurred. The number of these station reports in each of the eight regions was expressed as a percent of this total, and these percentages appear in their appropriate region in figure 2.

Note that the region of greatest frequency of no-hail thunderstorms is the south which is also the area of lowest summer hail averages. However, the average summer distribution of thunderstorms in Illinois [2] indicates Statewide maximization in the southern region with a secondary maximum along the western State boundary where thunder-report percentages are much lower than in the south. Thus, regional differences in the average thunderstorm distribution cannot serve as an explanation for the regional report percentage differences found in figure 2. Therefore, it appears that the meteorological conditions in southern and possibly northeastern Illinois may differ to some extent from those elsewhere in the State, and that these conditions may limit the production of hail in these two regions.

Synoptically, the thunderstorms on the 242 days with no hail were found to occur most frequently with cold front and air mass conditions. The total and average number of days by synoptic type are shown in table 3.

An examination of the printed *Daily Weather Maps* of the U.S. Weather Bureau for all of the thunderstorm days was performed to determine the one or two basic conditions which were responsible for the thunderstorms in Illinois. A total of 20 different combinations of conditions was found, but these combinations were grouped into six generalized types shown in table 3. For instance, the 79 no-hail days with cold front conditions include 63 cases caused solely by the front, 1 case of cold front with an occlusion, 2 cases with post-frontal over-running, and

TABLE 3.—*Synoptic types associated with thunderstorm days with and without hail during the crop-growing season*

Synoptic types	No-hail thunderstorm days			Hail-thunderstorm days		Average number of days with fronts
	Total days	Season average	Percent of total	Season average	Percent of total	
Cold front	79	8	33	27	51	36
Warm front	20	2	8	3	6	11
Stationary front	48	5	20	15+	28	31
Air mass	55	6−	23	4	8	----------
Low center	32	3	13	3	6	----------
Others	8	1−	3	1−	1	----------
Totals	242	25−	100	53	100	78

13 cases of pre-frontal squall lines. Pre-frontal was defined as being more than 50 miles ahead of the front. Air mass conditions were limited to cases where no front existed within 250 miles of the thunderstorm area on the day of occurrence. The low center typing included transient Lows without fronts, Lows with fronts, waves, and troughs. The category of "other" synoptic types refers to upper troughs and occlusions.

In table 3 the frequencies of no-hail days by synoptic types are also expressed as percentages of the 242 days. Similar percentages for the hail-thunderstorm days in Illinois during the 1951–60 period are shown for comparison. On a percentage basis, a greater frequency of no-hail thunderstorm days occurred with air mass, low center, and warm front conditions than did hail-thunderstorm days which were more completely associated with cold front and stationary front conditions. Huff [6] derived similar synoptic frequency percentages for 113 thunderstorm days between 1910 and 1960 with widespread hailstorms.

About 50 percent of the thunderstorm days caused by warm fronts, air mass conditions, and low centers did not have hail. However, 25 percent of the thunderstorm days associated with stationary fronts had no hail. Of the 35 thunderstorm days per season caused by cold fronts, on the average only 8, or 23 percent, were not hail days. In a climatological study of synoptic weather, Chiang [4] obtained data on the number of days with fronts occurring in Illinois during the 1945–59 period. Averages compiled for the growing season are presented in table 3 for comparison with the frontal frequencies for hail and no-hail thunderstorm days. Note that 75 percent of all days with cold fronts in Illinois had hail, whereas less than 50 percent of the days with stationary fronts had hail.

Another interesting observation pertaining to the 147 frontal cases associated with no-hail thunderstorm days was the lack of excessive temperature difference across the fronts, which in general indicated that most of these were relatively weak fronts at the surface. For instance, the average temperature difference across the 79 cold fronts was 4.4° F. as compared with 6.8° F. for the 270 cold fronts associated with the hail-thunderstorm days. Huff [6] reported that 50 percent of the cold front cases associated with widespread hailstorm days were pre-frontal in nature, whereas only 17 percent of the 79 cold front cases causing no-hail thunderstorms were pre-frontal. In general, the no-hail thunderstorms appeared to be associated with weaker synoptic systems.

A comparison of the synoptic types with the areas where associated thunderstorm reports were most prevalent revealed that on days with warm fronts the thunderstorms without hail occurred most frequently in central and northern Illinois. Chiang [4] has shown that warm fronts are most frequently located in central Illinois. Days of low center passages and air mass conditions had the greatest number of thunderstorm reports in the southern and central portions of Illinois. Chiang [4] also revealed that warm air mass conditions prevail in southern Illinois from 50 to 60 percent of the time in summer as compared with 30 percent of the time in northern Illinois, and that in summer low centers move most frequently across the southeastern and north-central portions of the State. Reports of thunderstorm days caused by either cold fronts or stationary fronts revealed no regional concentration within the State.

7. CONCLUSIONS

During the March–October thunderstorm season in Illinois on the average one-half of the days have thunderstorms and one-third of the days have hailstorms. During the crop-growing season, mid-May to mid-September, 63 percent of all days have thunderstorms and on 70 percent of these days, or 53 days on the average, hailstorms occur somewhere in Illinois. This areal frequency in growing-season hail days in Illinois is more than 50 times greater than the average point frequency of hail, and also is 2 to 5 times greater than any previously recorded areal frequencies for Illinois. The frequently used hail-thunderstorm ratio based on data recorded at a point cannot be considered as an adequate description of the occurrence relationships between hailstorms and thunderstorms.

Nearly one-third of all thunderstorm days in Illinois do not have hail observed at the ground, and during the growing season these no-hail thunderstorms are most frequent in southern Illinois. This ratio plus the fact that these no-hail thunderstorms frequently cover more than 15,000 square miles of Illinois on one day are findings which could be construed as being evidence that many thunderstorms do not produce hail aloft. This receives further support from Wilk's [17] findings and from the fact that the no-hail thunderstorms are associated more frequently with synoptic systems weaker than those associated with hail-thunderstorms.

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